Circular 84

STATE OF ILLINOIS
OTTO KERNER, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION
WILLIAM SYLVESTER WHITE, *Director*

Water Hardness and Domestic Use of Detergents

by LLOYD M. DE BOER AND THURSTON E. LARSON

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, *Chief*
URBANA
1961

14
(45352—10-61)

Printed by authority of the State of Illinois

REPRINTED FROM AND COPYRIGHTED AS A PART OF
JOURNAL AMERICAN WATER WORKS ASSOCIATION
Vol, 53, No. 7, July, 1961
Printed in U. S. A.

Water Hardness and Domestic Use of Detergents

Lloyd M. DeBoer and Thurston E. Larson

A paper presented on Mar. 22, 1961, at the Illinois Section Meeting, Chicago, Ill., by Lloyd M. DeBoer, Asst. Prof. of Marketing, College of Commerce, Univ. of Illinois, Urbana, Ill.; and Thurston E. Larson, Head of Chemistry Section, Illinois State Water Survey, Urbana, Ill.

EVERY housewife knows that the amount of soap or synthetic detergent she needs is determined, in part, by the hardness of the water she uses. This article reports the results of a tudy made to correlate varying degrees of water hardness with the detergent consumption of the people who use the water.. Detergent savings effected by water softening are compared to the costs of reducing water hardness.

Considerations of convenience, cleanliness, maintenance " of facilities, and life of clothes and linens are excluded from this study, although they are recognized :as economically important. The importance of water hardness tc commercial establishments, industries, and other establishments that use water for heating or air conditioning, is also beyond the scope of this inquiry.

Hardness Reduction and Removal

Aside from soap, which is a water softener as, well as a detergent, and from synthetic detergents, which usually include softening agents as additives in the commercial product, there are several methods of reducing the hardness of domestic water. One is treatment by the water utility, either with lime (and soda ash) or with ion exchangers (such as zeolite) using salt as the regenerant chemical. The other is by home treatment with ion-exchange units, either owned and regenerated by the homeowner or rented and serviced by local water-conditioning agencies.

The municipal water utility procedure rarely reduces the hardness below 70 ppm, and usually limits the hardness to 100 ppm, so that the calcium hardness protects the distribution sys-

rem against loss of pipe capacity and against corrosion, thus eliminating the possibility of rusty water.

Utility treatment and home treatment for hardness reduction readily supplement each other.[1]

Previous Studies

A comprehensive study on soap consumption and water quality was conducted by H. W. Hudson and A. M. Buswell in 1931.[2] Since then, economic changes, the almost complete replacement of soaps with synthetic detergents, the wide use of new man-made fabrics, and the automation of cleaning processes have necessitated a revised appraisal.

The Hudson-Buswell study was conducted by the personal interview method at retail stores to obtain com plete data on retail soap sales at four cities having different types of waters. After appropriate corrections for the surrounding trade area sales and other minor considerations, annual per capita soap consumption and costs were established. These figures 'were revised upward in 1948[3] by the application of a factor derived from the wholesale cost indexes for soap and soap products. At that time, synthetic detergents accounted for only a small percentage (about 12 per cent) of the domestic detergent consumption. At present, the national domestic sales of

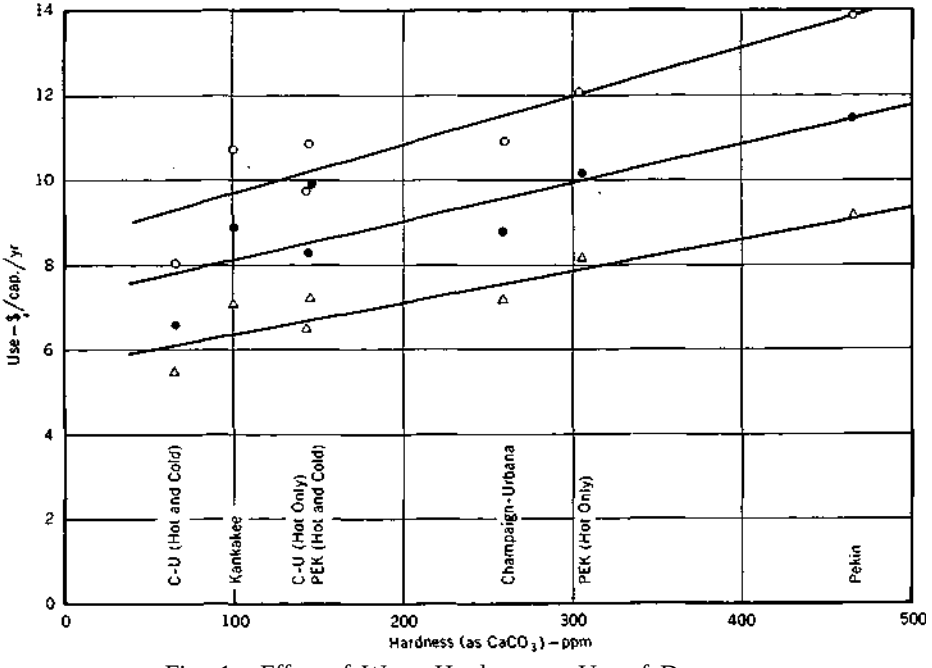

Fig. 1. Effect of Water Hardness on Use of Detergents

Savings per 100 ppm hardness for gross products (open circles) are $1.15; 90 cents per 100 ppm for total soap and synthetics (solid dots); 75 cents per 100 ppm for laundry detergents (triangles).

synthetics are roughly ten times the sales of soap.[4]

The advantages of synthetics with hard water are many, as demonstrated by their increasing use. As Aultman has pointed out,[5] however, their composition suggests that water hardness affects the quantity required for adequate cleaning. The heavy-duty, all-purpose products that comprise by far the largest segment of the market contain 30-50 per cent sequestering ingredients such as complex phosphates * to equal soaps in ability to remove dirt from heavily soiled clothes and in general cleaning.

These sequestering ingredients are also softening agents, because they react with calcium and magnesium, the hardness components of water. In hard water, therefore, these ingredients are decreased in effective concentration for their cleaning purpose. Thus more product is required in hard water than in soft water.

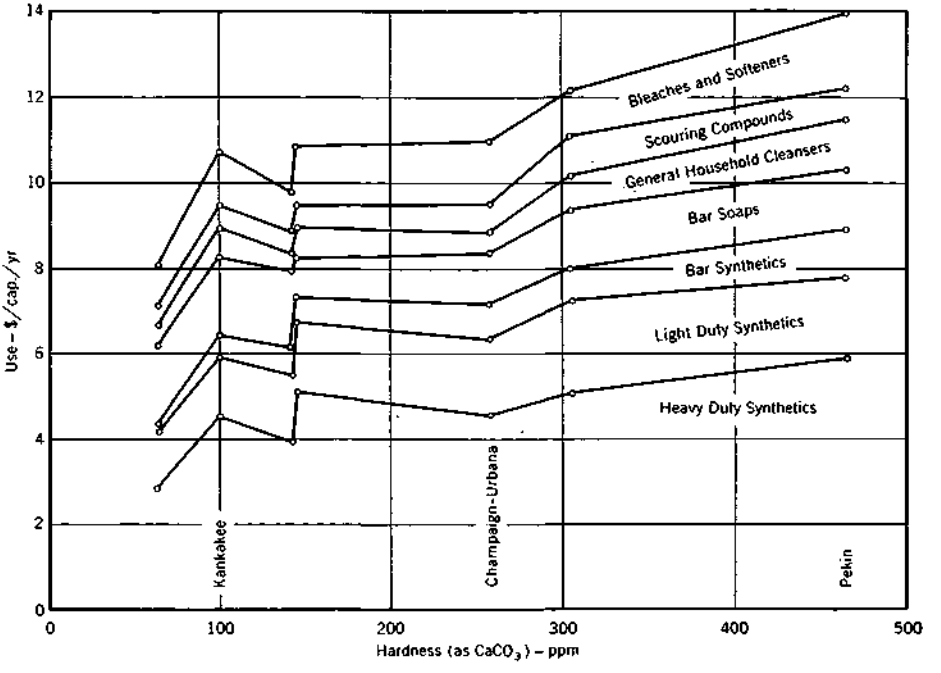

Fig. 2. Effect of Water Hardness on Use of Various Products

Heavy-duty synthetics comprise major portion of products used.

Because many families substitute or supplement synthetics and soaps with softening agents, scouring compounds, and bleaches, it is reasonable to expect that the consumption of these additives would also be related to water hardness. In this study, therefore, data on these products were also obtained.

* Usually sodium tripolyphosphate (STP) and tetrasodium pyrophosphate (TSPP), and more recently tetrapotassium pyrophosphate (TKPP) in liquid heavy-duty synthetics.

Method of Procedure

Three cities were chosen for the study: Kankakee (KKK), Champaign-Urbana (C-U), and Pekin (PEK), all in Illinois. At Kankakee, the water utility clarifies and softens water from the Kankakee River to a hardness of 100 ppm as well as chlorinating and treating the water for taste and odor removal.

At Champaign-Urbana, well water is treated for iron removal and is chlorinated. The weighted-average hardness, as determined from the pumpage and analysis of the water from wells used during the study, was 258 ppm.

At Pekin, no treatment is provided other than chlorination. The average hardness was determined from 48 samples collected twice monthly during the study, from five selected locations in the distribution system. Average hardness was found to be 465 ppm.

In each of these three communities a panel of households was selected by probability sampling procedures. The number selected in Kankakee was 169; in Champaign-Urbana, 274; and in Pekin, 230. More households were selected than were necessary, as it was anticipated that there would be drop-outs during the study. The number of

TABLE 1

Average Use of Products Per Capita Per Year

Product Classification	City and Type of Home Softening						
	C-U Hot & Cold	KKK None	C-U Hot*	PEK Hot & Cold	C-U None	PEK Hot*	PEK None
	Average use—$						
Heavy duty synthetics	2.84	4.54	3.94	5.11	4.59	5.07	5.85
Light duty synthetics	1.36	1.38	1.56	1.66	1.74	2.20	1.92
Bar synthetics	0.16	0.50	0.61	0.51	0.82	0.73	1.12
Dishwashing compounds	0.05	0.02	0.29	0.00	0.05	0.02	0.00
Heavy duty soap	0.46	0.19	0.24	0.00	0.06	0.01	0.05
Light duty soap	0.35	0.28	0.08	0.00	0.08	0.07	0.03
Bar soap	0.96	1.36	1.25	0.98	0.98	1.26	1.27
Household cleaners	0.45	0.69	0.36	0.71	0.50	0.83	1.22
Scouring compounds	0.49	0.58	0.53	0.50	0.68	0.90	0.74
Softening compounds	0.65	0.63	0.54	0.93	0.91	0.73	0.91
Bleaches	0.25	0.55	0.36	0.46	0.50	0.29	0.82
Total	8.02	10.72	9.76	10.86	10.91	12.11	13.93
	Average Cost—¢/oz						
Synthetics	1.94	1.82	1.89	1.84	1.84	1.86	1.88
Soaps	2.08	2.31	2.65	2.44	2.58	2.48	2.60

* Blend of 60 per. cent softened hot water with 40 per cent unsoftened cold water.

households selected in Champaign-Urbana and Pekin were greater than in Kankakee, so that a sufficient number who sottened some or all ot the water could be classed as separate panels. In addition to. dropouts, all households that did laundry for persons other than household members were eliminated in the ' correlation studies, as were those that used commercial laundries or laundermats.

Each household reported monthly, on a diary form, their purchases of the products included in this study. The time period covered by their reports was seven months, July 1959 to February 1960. The diary form was mailed to the household each month as a reminder to record each purchase. Purchase data were usually reported by brand of product, size,-and cost. At the start and at the end of the time period covered by the study, a complete-inventory of all soap and synthetic detergent products and other additives on hand was taken by trained interviewers. By use of these purchase data and inventory data, computations provided the amount and value of each class of product used by each household during the study.

The individual products used by the households were grouped " into twelve product classifications for analysis: light-duty soap, heavy-duty soap, bar soap, light-duty synthetic detergent, heavy-duty synthetic detergent, bar synthetic detergent, general household cleanser, scouring compound, dishwasher compound, shampoo, package softener, and bleach. Information from manufacturers on the. nature of their products and the type of cleaning job each was designed to. perform served as. the basis for this, classification so that each group would be reasonably homogeneous on these two points.

Shampoo purchase records and questionnaire data on use of beauty parlors were considered separately.

It became evident early in the proccess of evaluating results that the assumptions on the hardness of home softener effluents were not valid. Therefore, in both Champaign-Urbana and Pekin, the hardness of the hot and cold water to the laundry was determined at 35 homes.

Four homes at Pekin and two at Champaign-Urbana that reported both hot and cold water softened were found to" have softening only on hot water. After transfer of these panel members to, the proper classification, the remaining members under the hot and cold classification were visited twice for additional samples for hardness determinations.

For the softened hot water - classification, the average hardness was found to be 205 ppm at Pekin and 67 ppm at Champaign-Urbana. In the absence of definitive data it was arbitrarily assumed that 60 per cent hot water and 40 per cent cold water were

TABLE 2

Soap Use and Hardness*

City and Type Home Softening	Hardness (*ppm*)	Soap Use—Percentage of Consumption
Champaign-Urbana (hot and cold)	67	24.6
Kankakee (none)	100	17.6
Champaign-Urbana (hot)	143	15.6
Pekin (hot and cold)	145	8.6
Champaign-Urbana (none)	258	10.8
Pekin (hot)	306	10.8
Pekin (none)	465	9.9

* As distinguished from synthetics.

blended, or used alternately, for washing and cleaning purposes at homes where only hot water was softened. In this classification, therefore, hardness for Pekin was selected as 306 ppm and 143 ppm for Champaign-Urbana.

The average hardness of the samples from the hot and cold softened water classification was found to be 145 ppm at Pekin and 67 ppm at Champaign-Urbana.

The results of this study also showed a marked difference between the average hardness of home-owned softener effluents and serviced softeners. At Pekin, average hardness with home-owned softeners was 191 ppm, and 97 ppm with serviced softeners; at Champaign-Urbana, the average with home-owned units was 69 ppm, and 45 ppm with serviced units.

Results

Figure 1 shows the dollar costs and the savings by hardness reduction for average per capita use of all the products tabulated. It should be noted that within each of the six hardness classifications per capita use varied by factors as high as ten. The vertical range of the statistical standard error is therefore quite high.

The slope of the line of best fit as determined by the least square method using the 398 families, indicates the savings in gross products affected by hardness reduction to be $1.15 per capita per 100 ppm hardness removed. The 95 per cent confidence limit for the seven average values was 68 cents. Therefore, if Champaign-Urbana water is treated for a proposed 75 ppm hardness, the per capita savings would be $2.10 per year (if no home softener is presently used), or $7.35 per year for the average family size. At Pekin the per capita savings would be $4.20 per year if the hardness were reduced to 100 ppm. As previously explained, neither of these figures includes the many additional monetary savings, besides the convenience, that would result from hardness reduction.

Also in Fig. 1, the per capita use of laundry detergent products alone is indicated. This category excludes bleaches, softening agents, hand soaps, and scouring compounds. These products are often used for car washing,

TABLE 3

Shampoo Use and Beauty Parlor Patronage

City and Type of Home Softening	Hardness *ppm*	Income Over $6,600 %	Beauty Parlor		Shampoo
			Patronage %	Average Annual Expenditure $	Average Annual Use Per Capita—$
Champaign-Urbana (hot and cold)	67	77	41.2	72.00	.86
Kankakee (none)	100	28	24.8	41.58	1.32
Champaign-Urbana (hot)	143	58	42.8	84.33	1.00
Pekin (hot and cold)	145	46	38.5	51.60	.88
Champaign-Urbana (none)	258	39	21.7	56.61	1.33
Pekin (hot)	306	50	50.0	59.35	1.31
Pekin (none)	465	36	15.8	42.40	1.59

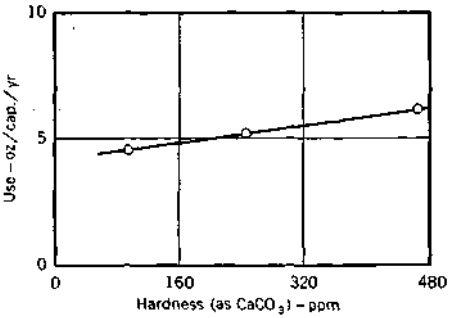

Fig. 3. Effect of Water Hardness on Use of Detergents by Unskilled, Craft, and Clerical-Sales Workers' Families

Use is for gross products excluding bleaches and softening additives by panel members that provided no home softening. Savings are 91 cents per cahita per 100 ppm hardness per year.

dish washing, and other cleaning purposes as well as for laundry. Here the slope of the line represents *75* cents savings per capita per year per 100 ppm hardness reduction. This is generally representative of the synthetic detergents and soaps exclusive of hand and bath products.

The middle line in Fig. 1 represents all soap and synthetic detergent products including bar products and general household cleansers. The savings by hardness reduction is indicated to be 90 cents per capita per year per 100 ppm hardness reduction.

The additive reported by the American Institute of Laundry and home economics experts to cause the greatest detrimental effect on clothes is bleach. The consumption of bleach increases, in general, with increasing hardness, reflecting the greater need for this additive when hard water is used.

Figure 2 and Table 1 show the breakdown of the use of gross products by product classifications. Synthetics represent most of the use, with the heavy-duty products predominating. The heavy-duty synthetics are the least expensive, costing 1.5 cents per ounce, whereas the light-duty synthetics at 2.6 cents per ounce, and bar synthetics at an average cost of 4—5 cents per ounce, have lesser general utility. The classification of heavy-duty detergents does not include the general utility products such as "Mr. Clean," "Handy Andy," and "Lestoil" which are also synthetic products and are often used for laundry purposes.

It will be noted in Table 1 that the use of light- and heavy-duty soaps is negligible in all three Pekin categories and in the Champaign-Urbana unsoftened water category. Of the total soap and synthetic detergent products, exclusive of general household cleansers, the percentage of soap use increases with decreasing hardness (Table 2).

Shampoo and Beauty Parlor

Approximately 90 per cent of the panel members reported shampoo purchases. Table 3 shows that the use of shampoo seems to bear a fair rela-

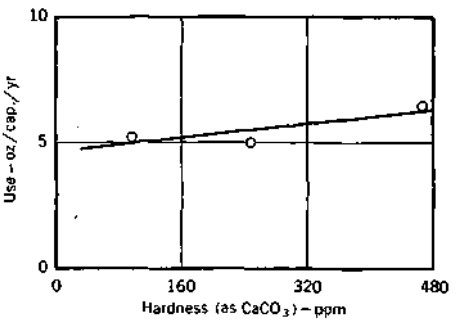

Fig. 4. Effect of Water Hardness on Use of Detergents by Families With Incomes of $4,200-$10,400

Use is for gross products excluding bleaches and softening additives by panel members that provided no home softening. Savings are 80 cents per capita per 100 ppm hardness per year.

ERRATA; On Figs. 3, 4, 5
Multiply "Use" scale by 100

tionship to water hardness. Any analysis of shampoo use, however, must also consider the 15-50 per cent of the households that also patronized the beauty parlor.

It will be noted that 38-50 per cent of those who soften their water patronized the beauty parlor and that 46-77 per cent of these groups were in higher income classifications. These groups coincide with the lower shampoo usage. Therefore, the shampoo data cannot be related to water hardness alone.

TABLE 4

Comparison of Socio-Economic Characteristics

Characteristic	C-U	PEK	KKK
	Panel Families in Each City—%		
Washer Used			
Automatic	59.6	61.2	61.0
Conventional	40.4	38.8	39.0
Income			
Under $4,200	19.9	17.6	28.6*
$4,200–10,399	61.0	72.0*	64.8
$10,400 and over	15.9*	9.9	6.7
Number of Children			
None	33.1*	26.0	30.5
One	24.5	24.7	15.2
Two–three	31.1	40.1	37.2
Four or more	11.3	9.2	17.1*
Age, Head of Household			
Under 30 years	15.2	22.6*	12.4
30–50 years	50.3	47.2	47.6
Over 50 years	33.1	28.2	37.1
Education, Head of Household			
Grade school	10.6	24.6	37.1
High school	39.8	56.4	41.9
College	27.8*	13.4	14.3
Post college	17.2*	2.8	2.9
Occupation, Head of Household			
Unskilled	11.3	12.0	16.2
Craftsman	33.8	45.1	37.2
Salesman, clerical	9.9	15.5	11.4
Professional, managerial	40.4*	15.5	21.0
Housewife	1.3	1.4	3.8
Retired	3.3	7.7	9.5

* Specific features of distinction.

Comparability of Panels

In a study of this type it is necessary that the panels in each community be comparable so that any differences in the consumption of soap and synthetic detergents established among them can be attributed to water hardness and not to differences in panel characteristics. Such comparison is made between the entire panels in each community irrespective of home, softening practices, because home softening practices also are determined to an important extent by the status and needs of the individual family as well as by water hardness.

The comparability of the panels was examined as to the type of washing machine used, total family income, number of children, and the age, education, and occupation of the head of the household. These factors are readily available from the study, which was designed to reveal important variations in consumption that might arise among families of a community when grouped by each of these characteristics.

The data in Table 4 indicate that each panel provides a reasonably good cross section for each characteristic, in that all major subgroups are adequately represented. They are particularly comparable as to type of washer used, with 60-61 per cent of all panel members in each community using an automatic washer. For each of the other characteristics, relatively more of the panel members in one community than in another belong to certain subgroups. Specific features of distinction are starred.

The table shows that considerable intra-correlation among these charac-

teristics is evidenced in Champaign-Urbana with its higher income, its higher education level, and its larger percentage of panel members with a professional or managerial occupation.

Further analysis of the characteristics of those panel members in Champaign-Urbana and Pekin that practice home softening indicates that they are more likely to own dishwashing machines and automatic washers, to have higher incomes, to be in older age groups, to have a college or post-college education, and to have a professional or managerial occupation. This appears to be a decided pattern for those who soften their water.

Analyses by Panel Characteristics

The data, grouped according to selected socio-economic characteristics, were examined to determine the existence of any relationships with the per capita consumption to total products. These analyses were made only for those who do not practice home softening. The number of panel members in many specific socio-economic groups, such as the clerical-sales occupation, was too small for meaningful analysis.

The per capita use for total products was found to be less for those using conventional washers than for those using automatic washers. The heavy- and light-duty soaps and synthetics would be the products most influenced by this factor. It is clear from Table 5 that there is much greater use of these products by those using automatic washers. This relationship is not significantly altered if general household products are included.

By grouping the craftsman, unskilled, and clerical-sales occupations, which represent 65-78 per cent of the panel members using unsoftened water/ a direct relationship . to hardness is indicated (Fig. 3) for ounces per capita use of products other than bleach and softening additives, and for dollars per capita per year use of gross products. Use by the professional-managerial occupations was greater at Kankakee and Pekin and less at Champaign-Urbana.

Similar but less conspicuous relationships are noted (Fig. 4) for the $4,200-$10,400 income group, representing two-thirds of the panel families at each city, and for the 30-50-year age group, representing 48-50 per cent of the families at each city (Fig. 5).

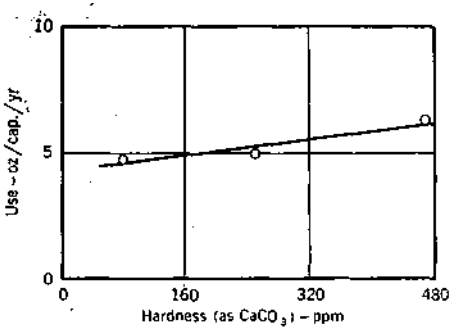

Fig. 5. Effect of Water Hardness on Use of Detergents by Families With Head of Household 30-50 Years Old[1]

Use is for gross products excluding bleaches and softening additives by panel members that provided no home softening. Savings are 96 cents per capita per 100 ppm per year.

There is a tendency for a slight decline in per capita consumption when there are more children in the family.

Inconsistent relationships between education of the head of the household with usage suggests that this factor has little influence on consumption.

Using the six selected socio-economic characteristics, the greatest number of families that had identical characteristics was found to be eight of the 398 families with more than 1,500 individuals in the three cities. These families use an automatic washer; the

head of the household has a craftsman occupation; he is 30-39 years of age; he graduated from high school; they have 2 children; and they have a family income of $6,600-$10,399. These families were also identical in family size (only one had a fifth member for 82 per cent of the study period), and none of them practiced home softening. Two families were from Kankakee and three were from each of the other communities. Thus, these families are as identical as they could be from the data used for description.

It is immediately clear from Fig. 6 that the total consumption of all products in dollars varies substantially among these eight families, from a low of $7.02 per capita per year to a high of $15.80. There is also substantial variation in many of the product classifications that go into this total. Heavy duty synthetics, the largest product group for all families but one, ranges from $2.87 to $9.90. Heavy-duty plus light-duty synthetics range from $4.28 to $10.85. Even among the less important product groups there is considerable variation. For example, one family is a heavy user of bar detergents, another of bar soap, another of scouring compounds, and still another of bleach and softening compounds. There was no consistency in total consumption among the families nor among the products consumed by any two of these families. Therefore, it is evident that no one family™ even within a given set of socio-economic characteristics, can be considered typical with regard to use of detergents.

Comparability of Water Quality

Considerable speculation may be made on the possible differences between the three cities. Aside from hardness, the general characteristics of the waters are different, as is noted in Table 6.

TABLE 5

Use of Light- and Heavy-Duty Snaps and Synthetics With Automatic and Conventional Washers

City	Hardness ppm	With Conventional Washer			With Automatic Washer		
		No.	oz/cap./yr*	$/cap./yr	No.	oz/cap./yr*	$/cap./yr
Kankakee	100	41	353	5.49	64	405	6.99
Champaign-Urbana	258	50	306	5.49	56	423	7.35
Pekin	465	48	365	6.64	48	545	8.54

* Excluding bleach and softening products.

The hardness of the Champaign Urbana water is carbonate with some sodium bicarbonate. On heating, carbon dioxide is released and calcium carbonate alone is precipitated in colloidal form.

Pekin water has appreciable noncarbonate hardness, but on heating and loss of carbon dioxide, again only calcium carbonate is precipitated, more of it than in Champaign-Urbana water at hot-water tank temperatures.

Kankakee water also has significant noncarbonate hardness, but the determined pH range of 9.2 to more than 10 means that no carbon dioxide will be released on heating; however, because the water is saturated with mag-

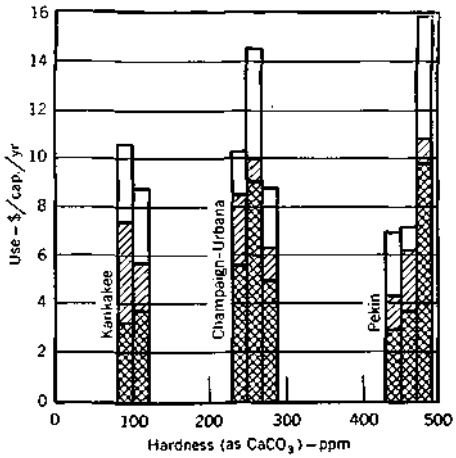

Fig. 6. Use by Eight Families Having Identical Socio-Economic Characteristics

Data show great variability in total use and in use of the different product classifications. Heavily shaded sections represent heavy-duty synthetics. Light-shaded sections represent light-duty synthetics. Blank sections represent all other uses.

nesium hydroxide as well as calcium carbonate, both will precipitate on heating. A considerable proportion of magnesium hydroxide will precipitate because of the high temperature coefficient for the solubility product constant.

One of the properties of precipitated magnesium hydroxide is its great adsorbing power. Also, contrary to the effect on calcium carbonate, trace concentrations of polyphosphates do not prevent the tendency of magnesium hydroxide to precipitate. Therefore, in laundry rinsing, for example, the precipitation of traces of magnesium hydroxide may adsorb traces of suspended soil and redeposit them onto the clothes. There are no data in the literature to confirm this hypothesis, nor are there data to disprove it.

Changes in Use and Cost

For comparative purposes, the total per capita soap and synthetic detergent use in ounces for this study is shown in Fig. 7 with that obtained in the Hudson-Buswell[2] retail sales study in 1931. The data indicate that the present day consumption is about 120 oz per capita per year less than 30 years ago. This might be attributed to the greater efficiency per unit weight of synthetics as compared to soaps. Consideration should also be given, however, to improved working conditions and to the diminished burning of coal, the smoke and dust of which may have formerly soiled things faster.

The cost of soap and detergent products, as for all products, has increased considerably since 1931, from 12 to 24 and 40 cents per pound; therefore, the present day costs for these cleaning products range from approximately

TABLE 6

Analyses of City Waters

Constituent	KKK	C-U	PEK
	Concentration—*ppm*		
Iron	trace	trace	trace
Manganese		0.0	trace
Calcium	20.7	57.0	123.1
Magnesium	11.7	28.0	46.0
Ammonium (NH_4)		3.0	trace
Sodium	44.9	35.0	9.2
Silica (SiO_2)	7.6	18.2	18.0
Fluoride		0.3	
Boron		0.4	
Chloride (Cl^-)	17	2.0	36.0
Nitrate (NO_3)		0.2	14.2
Sulfate (SO_4)		7.6	142.8
Alkalinity (as $CaCO_3$)	40	332	306
Hardness (as $CaCo_3$)	100	258	497
Total minerals	278	348	611
pH	9.7	7.5	7.3

$3.75 to $4.50 per capita per year more than in 1931 (Fig. 8). If there were no synthetics and if soaps were used at the same rate as in 1931 at a 1960 gross price of 32 cents per pound, the savings for 100 ppm hardness reduction would be $1.60 per capita per year. It is therefore evident that synthetics have particularly benefited users of harder water, although substantial savings of synthetics are to be realized with hardness reduction.

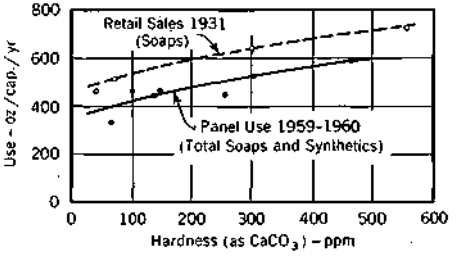

Fig. 7. Effect of Water Hardness on Weight Use of Soaps and Synthetics in 1931 and 1959-1960

Data show present consumption to be about 120 oz per capita per year less than 30 years ago.

Costs for Hardness Reduction

The gross savings indicated by this study may be compared with the per capita hardness reduction cost per 100 ppm per 1,000 gal by three methods of hardness reduction.

The average domestic consumption of water may vary 40—60 gpcd, of which it is generally assumed that about 27 gpcd, or 9,850 gal per capita per year, are used for purposes requiring softened water, such as laundry, bathing, cleaning, and cooking.

The gross purchase savings in additives per capita per 100 ppm hardness reduction have been indicated as $1.15 per year, or per 9,850 gal, which is approximately 11.7 cents per 100 ppm per 1,000 gal used for purposes requiring softened water.

Municipal Treatment

Municipal treatment, of course, processes all water and treats for purification, iron removal, taste and odor control, and corrosion prevention. The cost allocated to softening may vary from 5 cents to 15 or 20 cents per 1,000 gal, depending on the hardness removal,- the size • of the plant, and the degree of treatment for other improvements.

The effective . cost of municipal hardness reduction may be calculated by the following equation:

$$\frac{100AE}{BC} = \text{cents per 100 ppm per 1,000 gal}$$

in which A is cost of water charges allocated to hardness reduction in cents per 1,000 gal; B, average daily per capita use of water only for purposes requiring soft water in gallons; C, reduction of hardness in parts per million; and E, average daily per capita water use in gallons.

Therefore, at a 5-cent cost for hardness reduction from 250 to 75 ppm, and a per capita water use of 50 gpcd (of which 27 gpcd are for softened water purposes), the increment for hardness reduction would be 5:3 cents per 100 ppm per 1,000 gal.

If the hardness reduction were 400 ppm at an allocation of 20 cents per 1,000 gal for municipal treatment, the effective cost would be 9.3 cents per 100 ppm per 1,000 gal.

Home Softening

The usual commercial salt requirement for regeneration is about 0.4 or 0.5 lb per 1,000 grains of hardness, and for domestic home-owned softeners 1-2 lb per 1,000 grains is usually used in order to obtain minimum fre-

quency of regeneration. The minimum salt requirement for the regeneration of water softeners is 0.3 lb per 1,000 grains. This figure is based on proper application and backwashing with certain exchange materials of high regeneration efficiency at this level.

The per capita cost of salt may be calculated from the following equation:

$5.85AS$ = cents per 100 ppm hardness reduction per 1,000 gal

in which A is cost of salt in dollars per 100 lb; and S, salt use in pounds per 1,000 grains of hardness reduction.

Assuming that the regeneration step takes place at the time that the exchange capacity of the softener becomes exhausted, a minimum of 1.75 lb of salt is required for each 100 ppm hardness per 1,000 gal of water. At a domestic price of $2.00 per 100 lb, the minimum cost of salt may, be calculated to be 3.5 cents per 100 ppm hardness reduction per 1,000 gal. With an average home use of 1 lb salt per 1,000 grains, the cost would be 11.7 cents per 100 ppm hardness reduction per 1,000 gal.

Because the salt requirements do not represent the total cost of home softening, an estimate for amortization of the water softener should be included. The amortization cost may be calculated from this equation:

$$\frac{100{,}000\left[\left(\frac{A}{E}\right) + .025A\right]}{3.65BCD} = \text{cents per 100 ppr per 1,000 gal}$$

in which A is cost of softener in dollars; B, daily per capita use of softened water in gallons; C, hardness of water in parts per million; D, number of household members; and B, life of softener in years.

and the lost interest on the investment is 5 per cent per year.

At a softener cost of $250 and at a 10-year amortization period, this cost would be about $31.25 per year (depreciation plus 5 per cent on investment). For a four-member family using 27 gpcd of.'softened water, the cost would be 80, cents per 1,000 gal. If the water had 250 or 500 ppm hardness, the cost would be 32 or 16 cents, respectively, per 100 ppm hardness reduction per 1,000 gal. For a two-member family these figures would be doubled. The true cost of home softening is the sum of the salt requirement and the amortization cost.

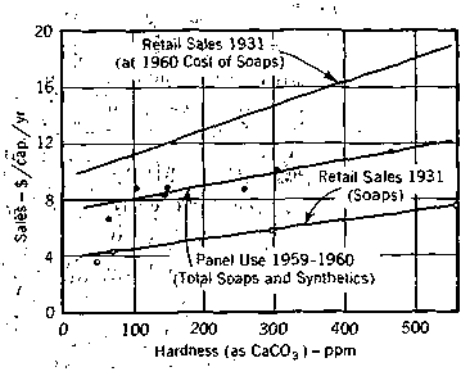

Fig. 8. Effect of Water Hardness on Sales of Soaps and Synthetics in 1931 and 1959-1960

Data show present sales range from approximately $3.75 to $4.50 per capita per year more than in 1931.

Serviced Softening

The charges for serviced softening include the cost of salt, the rental or amortization of the softener, and service.

The cost of serviced softening per 100 ppm hardness reduction per 1,000 gallons may be calculated from the following equation:

$$\frac{100{,}000A}{3.65BCD} = \text{cents per 100 ppm per 1,000 gal}$$

in which A is annual service charge in dollars; B, daily per capita use of

softened water in gallons; *C*, hardness of water in parts per million; and *D*, number of household members.

Thus for a family of four using 27 gpcd with 250 ppm hardness water and a service charge of $60 per year, the cost is 61 cents per 100 ppm hardness reduction per 1,000 gal, and for a family of two with 200 ppm hardness and a service charge of $42 per year, the comparable cost is $1.07.

Thus the annual per capita cost per 100 ppm hardness reduction can be determined by multiplying the calculated cents per 100 ppm hardness reduction per 1,000 gal by 9.85.

Conclusions

1. The savings for soaps, synthetics, general household cleansers, scouring compounds, bleaches, and other additives used were found to be $1.15 per capita per year per 100 ppm hardness reduction. Municipal treatment for hardness reduction can normally be expected to result in detergent and additives savings of more than the cost increment for treatment when the domestic per capita consumption is near 40-60 gpd.

2. The general replacement of soap with synthetic detergents has introduced a decrease in pounds per capita consumption since 1931. This alone has largely resulted in a savings at Kankakee, Champaign-Urbana, and Pekin approaching $3.80, $4.75, and $6.10 per capita per year, respectively, if soaps were still the only detergent products available.

3. The percentage of synthetic detergent use, relative to soaps, increases with greater hardness in water used.

4. The major cost of home softening is in amortization and service charge, and decreases with use of harder waters and with increasing use of the softened water. This is similar to the amortization cost that may be attributed to automobile driving mileage per year; because the depreciation per year is a fixed charge, the cost per mile of amortization decreases with more miles.

References

1. LARSON, T. E. Municipal and Home Water Softening. *Jour. AWWA*, 45:557 (Jun. 1953).
2. HUDSON, H. W. & BUSWELL, A. M. Soap Consumption and Water Quality. *Jour. AWWA*, 24:859 (Jun. 1932).
3. LARSON, T. E. Interpretation of Soap Savings Data. *Jour. AWWA*, 40:296 (Mar. 1948).
4. WEAVER, P. J. Detergent Research Review. /. *WPCF*, 32:288 (1960).
5. AULTMAN, W. W. Synthetic Detergents as a Factor in Water Softening Economics. *Jour. AWWA*, 50:1353 (Oct. 1958).